Detector development for very long baseline neutrino experiments

LDRD #06-004, midyear review 8/16/2007

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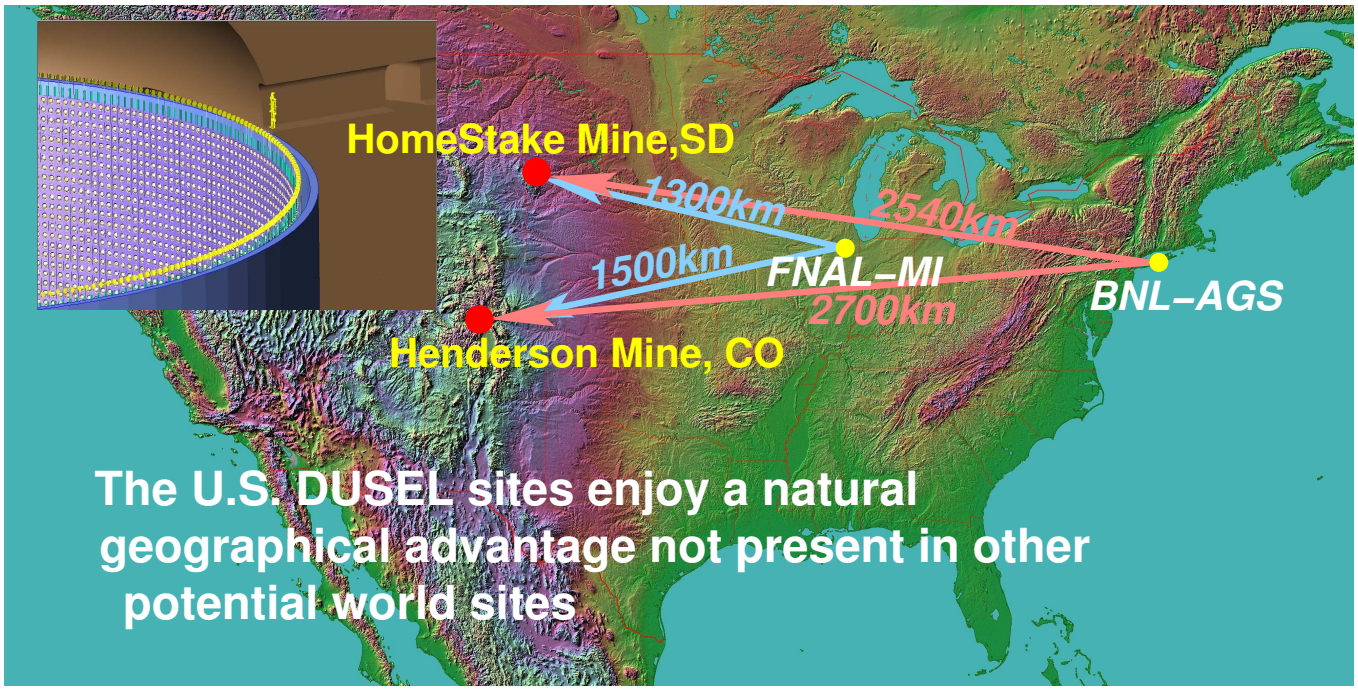
Proposal



Develop new concepts for very large (~ 500 kT) multipurpose detectors to be used for very long baseline neutrino experiments using a wide band super-neutrino beam directed to a future NSF Deep Underground Science and Engineering Laboratory (DUSEL).

List of Accomplishments

- **The basic idea of sending a high intensity wide-band conventional neutrino beam to a very large underground detector $>$ 1000km has now been confirmed** *as the best option for searching for CP violation in the neutrino sector and resolving the mass hierarchy.*
- **Key participant in the DUSEL process. Completed with Homestake mine chosen by an NSF panel as the DUSEL site.**
- **Examination of FNAL based beam and detector simulations completed with the US Long Baseline Neutrino Expt. report.**
- **Preliminary proposal for a 300 kT detector in Homestake complete. Document is part of the US Long Baseline study.**

DUSEL Process & Status

- NSF S1 (Science Case) process has been completed with a report submitted. M. Diwan was one of the group leaders.
- NSF S2 (Site Specific Proposals) process complete with Homestake and Henderson site proposals chosen. M. Diwan is on the executive committee of Homestake and one of the Senior Personnel.
- Homestake CDR completed. M. Diwan is one of the authors.
- Homestake-DUSEL is lead by LBL with M. Diwan chosen as one of the senior personnel due to BNL's R&D contributions.
- On July 10, 2007 NSF selects Homestake mine as the DUSEL site. BNL's contributions to the large detector R&D was an important factor.

  http://www.nsf.gov/news/news_summ.jsp?cntn_id=109694

U.S. Long Baseline ν Study

- **Sally Dawson (BNL) and Hugh Montegomery (FNAL) launched a joint study in late 2005.** *Milind Diwan was selected as co-leader.*
- **On March 3, 2007, the Neutrino Advisory Group (NuSAG) of HEPAP/NSAC was charged with addressing the next generation neutrino beam and detectors. NuSAG requests input from the Study.**
- **Several meetings and many documents generated. All are at http://nwg.phy.bnl.gov/fnal-bnl.**
- *Final report released May, 2007.* **BNL-77973-2007-IR, FNAL-0801-AD-E, arXiv:0705.4396. This report is a major achievement of this LDRD.**

  US LBν Study results heavily utilized in the preperation of the NuSAG report.

  Released July 27th, 2007 at http://www.science.doe.gov/hep/hepap_report.shtm
- **Numerous presentations by M. Diwan, M. Dierckxsens, M. Bishai. In the U.S., Europe (various countries), Japan.**

Homestake Detector Proposal

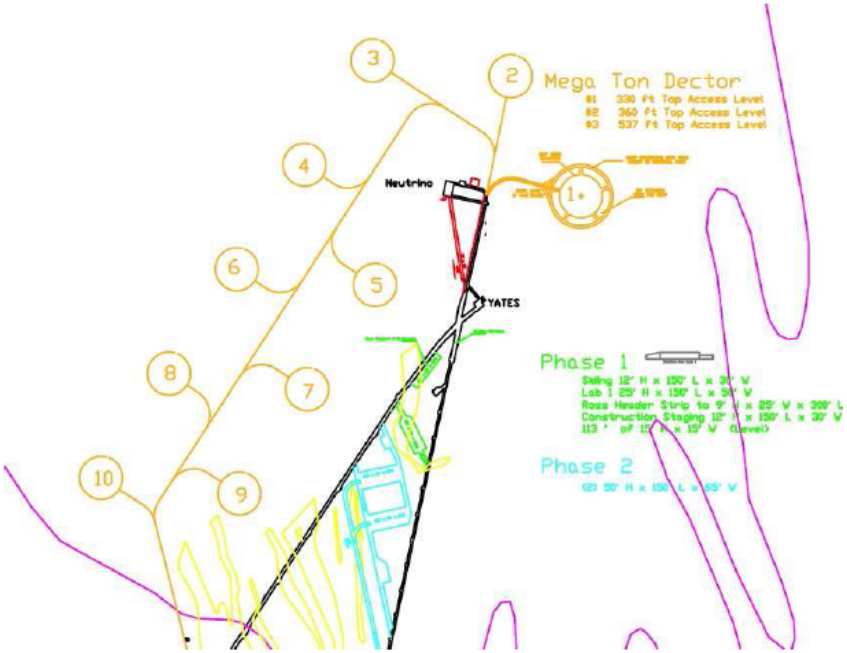
Modular detector system deployed in the 4850 ft level.

Detector module is 100kT fiducial Water Cerenkov (53m dia/h)

25% PMT coverage with 12” PMTs

Cosmic rate is $\sim$ 0.1Hz

BNL-76798-2006-IR



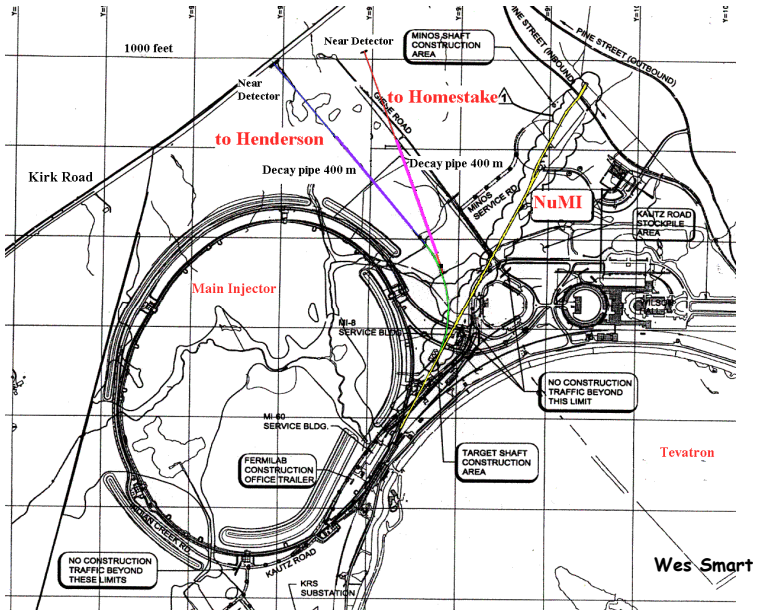
Initial detector is 3 modules - space can be planned for 10

Cost estimate is $115M/module

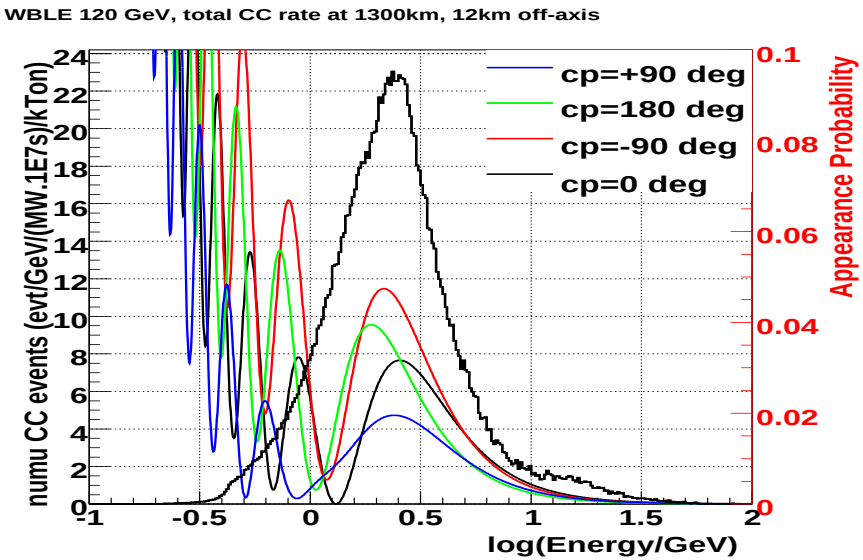
6 yrs construction to first 100 kT. 8 yrs to full 300 kT.

FNAL beam & detector simulations

DUSEL beamline at FNAL



Simulations of FNAL-MI Beam:



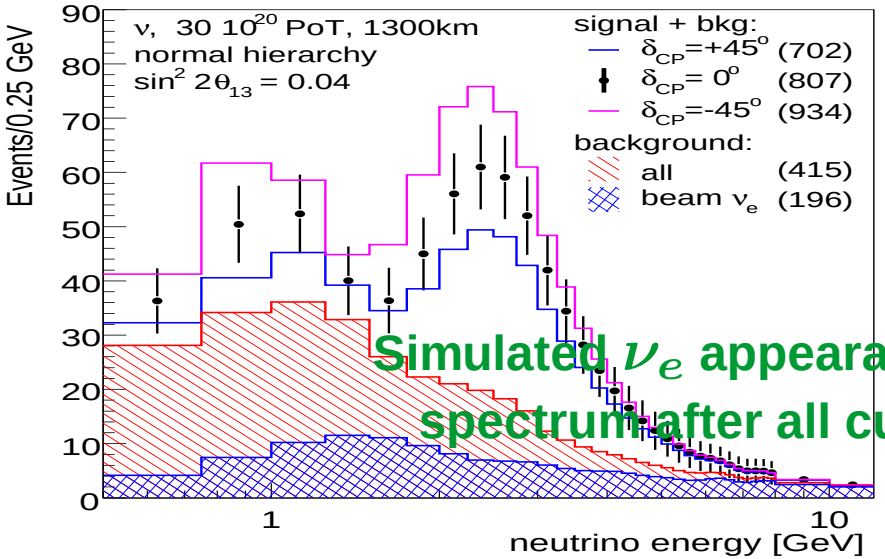
Water Cerenkov detector simulations:

300kT water Cerenkov .

120 GeV wide-band @ 1300km

1.2 MW beam $\times$ 3 yrs

$$P(\nu_\mu \rightarrow \nu_e) = 2\% \longrightarrow$$



Simulated ν_e appearance spectrum after all cuts

Sensitivity comparison

The sensitivity reach is given as

the *minimal* value of $\sin^2 2\theta_{13}$ at which 50% of δ_{cp} values have $\geq 3\sigma$ reach for the choice of mass hierarchy with worst sensitivity.

Total exposure assumes equal amounts of ν and $\bar{\nu}$:

Beam	Baseline	Detector	Exposure (MW.yr*)	$\theta_{13} \neq 0$	CPV	$sign(\Delta m^2_{31})$
NuMI ME, 0.9°	810 km	NOνA 20 kT	6.8	0.015	$>$ 0.2	0.15
NuMI ME, 0.8°	810 km	LAr 100 kT	6.8	0.002	0.03	0.05
NuMI LE, 0.8°, 3°,	810,700 km	LAr 2 $\times$ 50 kT	6.8	0.005	0.04	0.04
WBLE 120GeV, 0.5°	1300km	LAr 100 kT	6.8	0.0025	0.005	0.006
WBLE 120GeV, 0.5°	1300km	WCe 300 kT	6.8	0.006	0.03	0.011
WBLE 120GeV, 0.5°	1300km	WCe 300 kT	13.6	0.004	0.012	0.008

The proposed very long baseline expts improve CPV sensitivity by at least x10

The best sensitivities are a wide-band beam FNAL-DUSEL expt.

NuSAG Recommendations

Recommendation 1. The US should prepare to proceed with a long baseline neutrino oscillation program to extend sensitivity to $\sin^2 2\theta_{13}$, to determine the mass ordering of the neutrino spectrum, and to search for CP violation in the neutrino sector. Planning and R&D should be ready for a technology decision and a decision to proceed when the next round of results on $\sin^2 2\theta_{13}$ becomes available, which could be as early as 2012. A review of the international program in neutrino oscillations and the opportunities for international collaboration should be included in the decision to proceed.

Recommendation 2. Research and development towards an intense, conventional neutrino beam suitable for these experiments should be supported. This R&D may be to support intensity upgrades to the existing NuMI beam, as well as development of a new beam directed towards DUSEL, which would likely employ the wide-band beam approach.

Recommendation 3. Research and development required to build a large water Cherenkov detector should be supported, particularly addressing questions of minimum required photocathode coverage, cost, and timescale.

Recommendation 4. A phased R&D program with milestones and using a technology suitable for a 50-100 kton detector is recommended for the liquid argon detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended.